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(54) Abstract Title

Spring support systems for a displacer piston of a Stirling Engine

(57) A Stirling Engine in which a free displacer piston 12 reciprocates in a cylinder 11 has at least one spring support arrangement, provided at a cooled end of the cylinder, which acts between a flange 28 of the cylinder and a flange 22 or abutment 20 of the displacer piston 12, to mount and centre the displacer piston 12 within the cylinder 11. The spring support arrangement may comprise at least two pre-compressed helical compression springs 27,32 or at least two pre-extended helical extension springs 27,32 arranged in series or co-axially so that the biassing force of one spring counters the biassing force of the other. The ends of the helical compression springs may be ground flat and parallel.

FIG. 2.

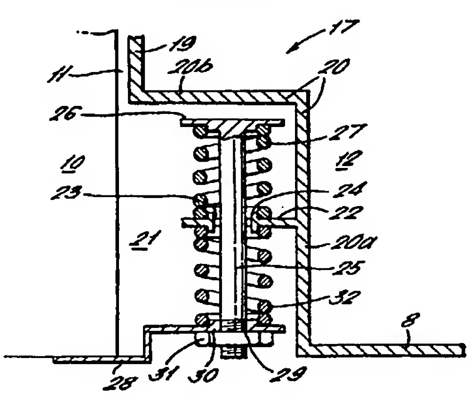
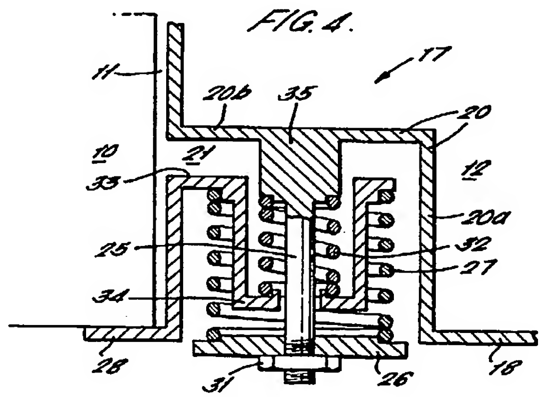


FIG. 4.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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IMPROVEMENT IN FREE PISTON STIRLING ENGINES

The present invention relates to improvements in free piston Stirling engines and more particularly to a spring mounting system for the displacer system of such an engine.

Stirling engines are well known in the prior art and normally comprise two reciprocating pistons, one called a displacer piston and one called a power or working piston which are coupled together by means of a crankshaft from which the power output is drawn. The significant feature of a Stirling engine is that it receives heat through the wall of the cylinder (rather than internally as in an internal combustion engine) and heat is removed from the cooler of the engine. As a consequence of the resulting temperature difference between the heater and cooler, some of the thermal energy is converted into mechanical energy by the engine, appearing as output shaft rotational energy, and can be applied to a mechanical load.

The majority of Stirling engines comprise a two piston arrangement of a displacer piston and a working piston and Stirling engines are commonly arranged such that the displacer piston has a relatively long stroke, the stroke being larger than the diameter of the piston. This is the accepted practice for Stirling engines.

The Harwell Laboratories in the United Kingdom produced a Stirling engine which replaced the working piston of a normal Stirling engine with a steel diaphragm member which flexes instead of reciprocating.

In a Harwell type of free piston Stirling engine the two pistons are not connected to any crank mechanism, but are instead typically supported from the outer casing of the engine each by a spring system. The engine casing also is mounted on a spring

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FIG. 1.

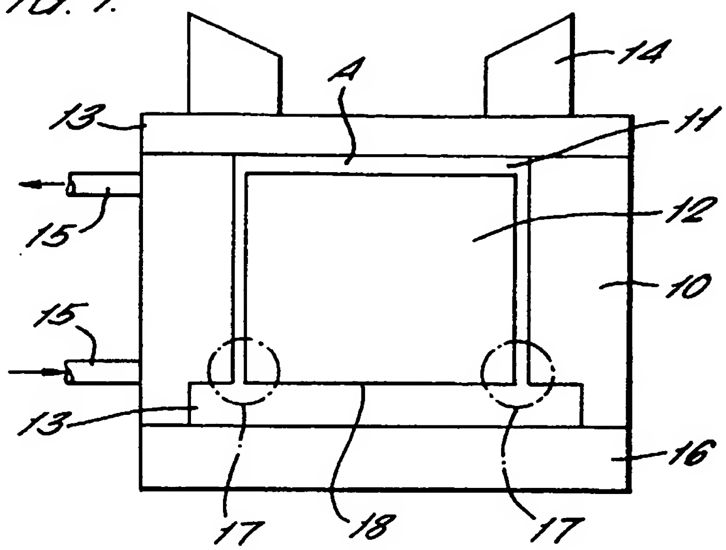

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FIG. 2.

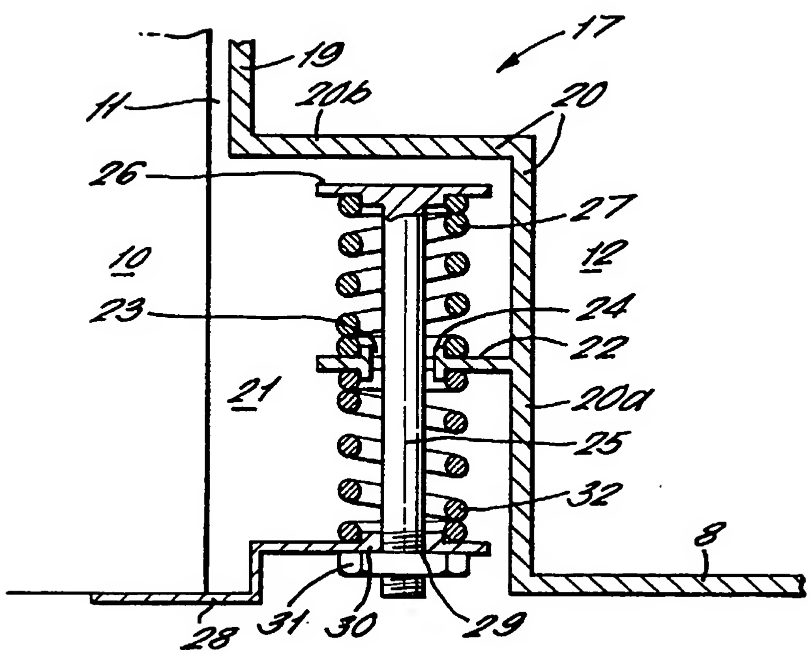

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FIG. 3.

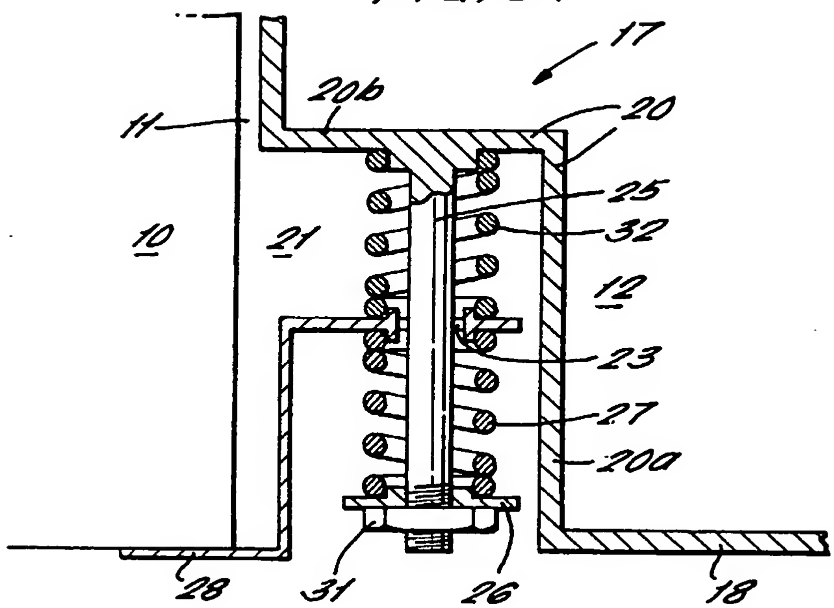
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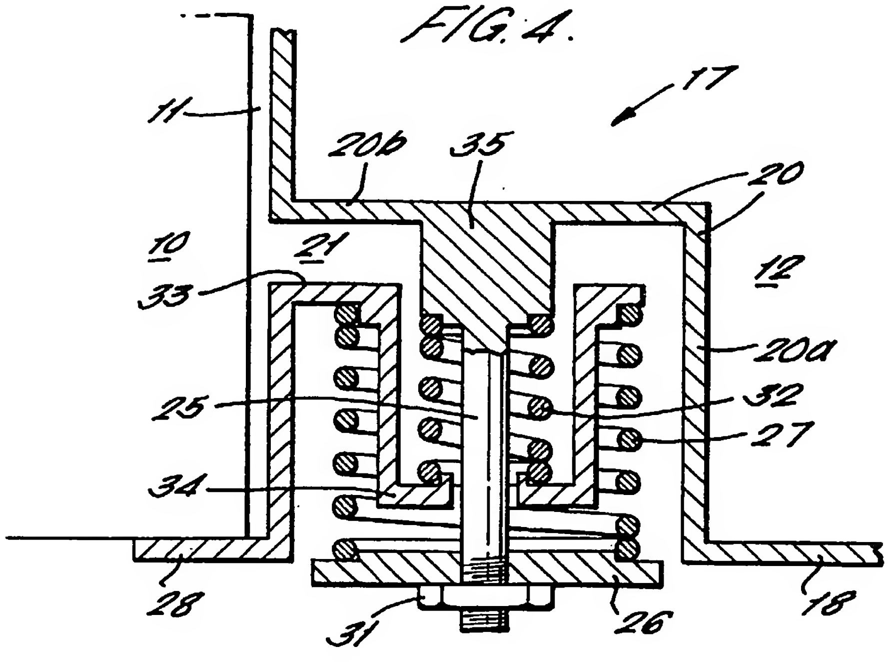
FIG. 4.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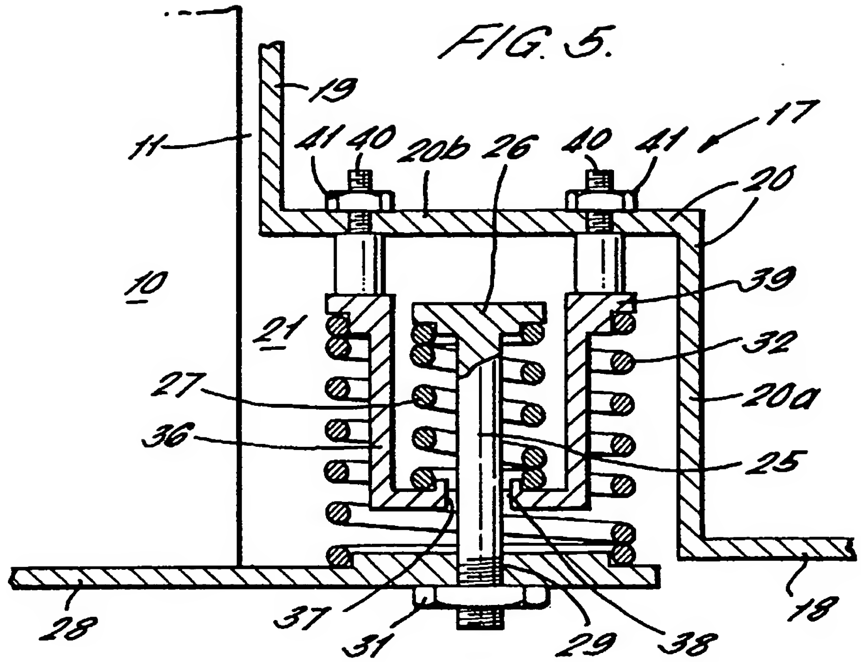

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FIG. 5.

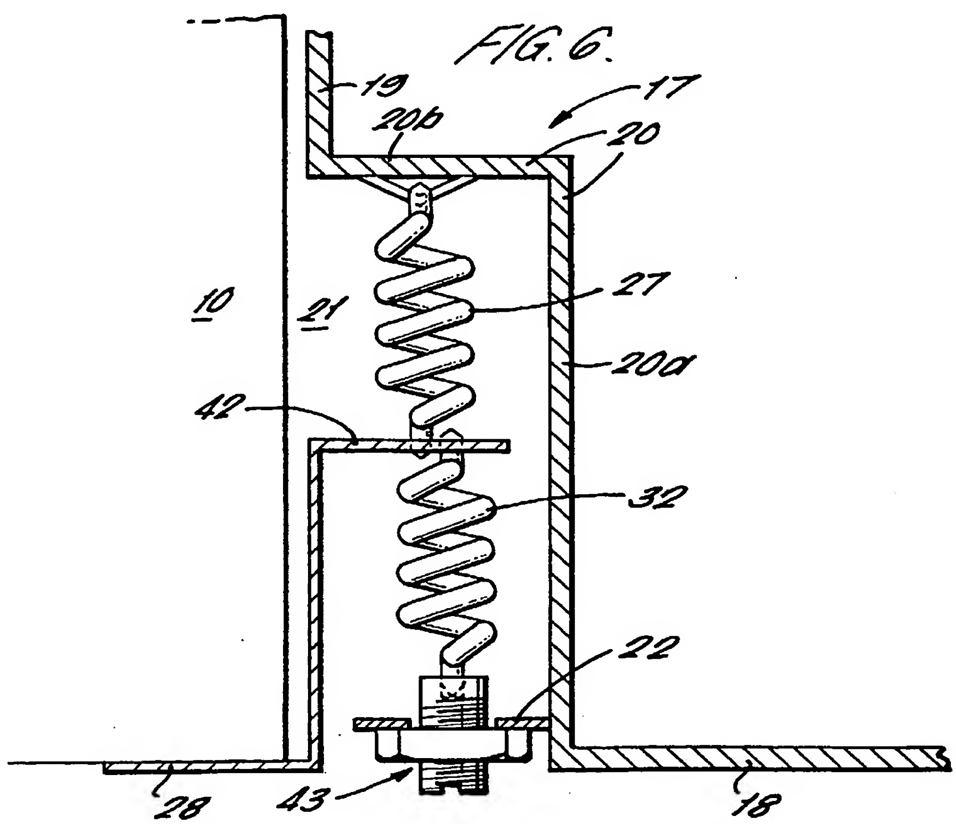

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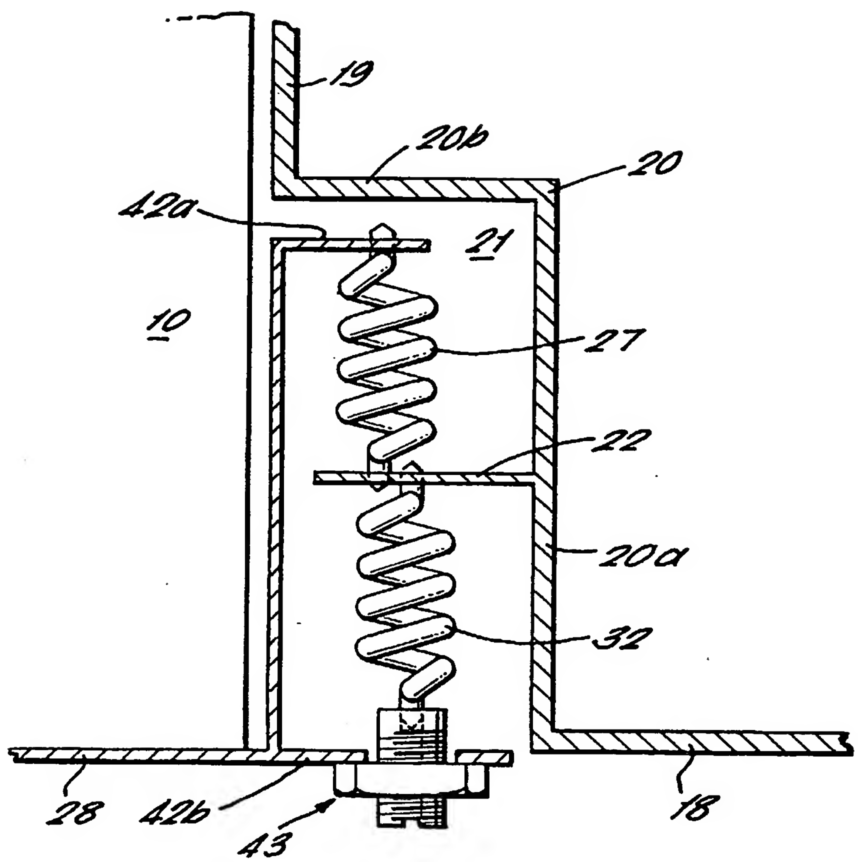
FIG. 6.

FIG. 7.



system typically supported by a solid base. Oscillations of the two pistons and casing occur when thermal energy is passed through the engine, producing a temperature drop between the heater and cooler of the engine as it does so. The oscillations of these three components are sinusoidal and at the same frequency but are not in phase. The frequency of oscillation is determined by many factors, but is mainly a function of the displacer piston's natural frequency of operation (this in turn is a function of its mass, supporting spring stiffness and the effect of any damping forces).

Mechanical energy can be directly drawn from either of the pistons, or the casing. However, the mechanical energy is in the form of reciprocating motion. Furthermore as the power output of the engine changes so the amplitude of the reciprocating motion changes. Because it is difficult to efficiently convert variable amplitude reciprocating shaft movement to a rotational form, the reciprocating power take off shaft is usually arranged to drive a linear generator directly.

The frequency of oscillation and working stroke of the reciprocating power take off shaft are important as the magnitude of these parameters inversely determines the size, and hence cost, of the generator. Thus it is usual to take the shaft power from the power piston, which is designed to have the largest stroke of the three components.

The spring support system of the displacer piston is a crucial engine component. One or more spring systems may be used depending upon the design of engine, but it is usual to have three or four spring support systems for the displacer piston. Each spring system must be compact to minimise dead spaces within the engine, and it is also advantageous if the spring system is cheap, simple to construct and reliable.

The use of standard spiral springs offers advantages in these respects. However standard spiral springs are designed to work only in either compression or extension, but not both. In operation, the displacer piston moves in two directions (up and down the cylinder) and thus a single support spring would need to work in both compression and extension modes. Operating a standard spiral wound spring in the mode for which it is not designed will result in a varying spring stiffness (which will affect displacer piston frequency and its stroke) and may also reduce the spring's life. In addition there are difficulties associated with attachments to the end of the spring when using a standard spiral spring out of its normal operating mode.

For this reason if standard spiral wound springs are to be used they must be prestressed so that they only operate in the mode for which they are specified. Thus if extension springs are used, they must be prestressed by extending them a pre-determined amount, sufficient that the maximum movement of the displacer piston does not allow them to reach their free unextended length. Similarly, if compression springs are used they must be sufficiently precompressed so that full movement of the displacer piston does not cause them to reach their free length.

It is an object of the present invention therefore to provide a spring mounting system for the displacer piston to overcome these problems.

The invention therefore provides a Stirling engine having a cylinder block defining a cylinder, a displacer piston located in said cylinder and at least one spring mounting means provided to mount the displacer piston in the cylinder such that the displacer piston is free to oscillate in the cylinder, wherein the spring mounting means comprise at least two spring members arranged to bias the displacer

piston towards a resting position with respect to the cylinder block, wherein the spring members are arranged such that the biassing force of one spring member counters the biassing force of the other spring member.

The spring members are preferably arranged in series.

The spring members are preferably arranged co-axially.

In a preferred embodiment the spring members are compression springs.

The cylinder block is preferably provided with at least one abutment member for at least one of the spring members and the displacer piston is provided with at least one abutment member for at least one of the spring members, wherein one of the cylinder block and displacer piston abutment members provides opposing abutment surfaces for two spring members, and in which one spring member extends between the cylinder block and displacer piston abutment members.

The at least one abutment member of the displacer piston may comprise flange means extending radially outwards from the displacer piston.

The at least one abutment member of the displacer piston may comprise a portion of a radially extending wall of the displacer piston.

The at least one abutment member of the displacer piston is preferably a member projecting from a radially extending wall of the displacer piston.

The at least one abutment member of the displacer piston is preferably provided by a cup member having an outwardly extending radial lip providing one abutment surface and having a base defining an opposing abutment surface.

The at least one abutment member of the cylinder block comprises flange means extending radially inwards from the cylinder block.

Preferably a further abutment member is attached to a shaft, which shaft extends slidingly through one of the displacer piston or cylinder block abutment members, in which a second spring member extends between either the displacer piston abutment member or the cylinder block abutment member and the shaft abutment member to bias them apart, wherein the shaft abutment member is constrained from moving more than a predetermined distance from either the cylinder block or the displacer piston abutment member.

The spring member may alternatively be extension springs.

One spring member preferably extends between attachment means on the displacer piston and attachment means on the cylinder block, and a second spring member extends between either of said attachment means on the cylinder block or on the displacer piston and secondary attachment means on either the displacer piston or the cylinder block respectively.

Preferably the attachment means on the displacer piston are located on a portion of a radially extending wall of the displacer piston.

The attachment means and/or the secondary attachment means on the displacer piston may comprise a flange member extending radially outwards from the displacer piston.

The attachment means on the cylinder block may be located on a flange member extending radially inwards from the cylinder block.

The secondary attachment means on the cylinder block are preferably located on a flange member extending radially inwards from the cylinder block.

The invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

Fig. 1 is a schematic cross-sectional side elevation of a Stirling engine having a free displacer piston;

Fig. 2 is an enlarged view of the spring mounting area of Fig. 1 showing a spring mounting according to the present invention;

Figs. 3 to 5 are alternative embodiments of the spring mounting arrangement of Fig. 2; and

Figs. 6 and 7 are alternative embodiments of the spring mounting arrangement of Fig. 2, utilising extension instead of compression springs.

Referring first to Fig. 1 the Stirling engine comprises a cylindrical cylinder block 10 defining a cylinder 11.

A free displacer piston 12 is provided to move reciprocally in the cylinder 11.

A cylinder head closes off the top of the cylinder 11 and defines, with the cylinder block 10 and an upper plate of the displacer piston 12, a variable valve chamber A. The cylinder head abuts a heat exchanger block 13, which is heated by means of heater tubes 14.

Attached to the cylinder block 10 is a diaphragm 16, which is made of a material which is able to flex or is fully flexible The diaphragm 16 defines, with the cylinder block 10 and a bottom plate of the displacer piston 12, a variable volume chamber B.

Coolant inlet and outlet tubes 15 are provided to enable heat removal from the cylinder and the working fluid in the manner described in GB-A-2298903.

A plunger is connected to the diaphragm to move with the diaphragm. The plunger is connected to a linear alternator, which is located in a housing defining a bounce chamber.

Referring now to Fig. 2, this shows an enlargement of the displacer piston mounting area 17 (left hand side). The bottom plate 18 of the displacer piston 12 has a smaller diameter than that of the side walls 19. The bottom plate 18 and the side wall 19 are connected by an inwardly stepped portion 20 being L-shaped in cross-section. This stepped portion 20 defines, with the side walls of the cylinder block 10 defining the cylinder 11, a small annular chamber 21 in which one or more of the spring mounting systems are located. The number of spring mounting systems used depends upon the design of the engine. It is preferred to have three or four spring mounting systems for each displacer piston 12.

For each spring system, a flange 22 extends from the displacer piston 12. In this embodiment the flange 22 extends radially from a first wall 20a of the stepped portion, said first wall extending to a parallel to the displacer piston side wall 19.

A cylinder head closes off the top of the cylinder 11 and defines, with the cylinder block 10 and an upper plate of the displacer piston 12, a variable valve chamber A. The cylinder head abuts a heat exchanger block 13, which is heated by means of heater tubes 14.

Attached to the cylinder block 10 is a diaphragm 16, which is made of a material which is able to flex or is fully flexible The diaphragm 16 defines, with the cylinder block 10 and a bottom plate of the displacer piston 12, a variable volume chamber B.

Coolant inlet and outlet tubes 15 are provided to enable heat removal from the cylinder and the working fluid in the manner described in GB-A-2298903.

A plunger is connected to the diaphragm to move with the diaphragm. The plunger is connected to a linear alternator, which is located in a housing defining a bounce chamber.

Referring now to Fig. 2, this shows an enlargement of the displacer piston mounting area 17 (left hand side). The bottom plate 18 of the displacer piston 12 has a smaller diameter than that of the side walls 19. The bottom plate 18 and the side wall 19 are connected by an inwardly stepped portion 20 being L-shaped in cross-section. This stepped portion 20 defines, with the side walls of the cylinder block 10 defining the cylinder 11, a small annular chamber 21 in which one or more of the spring mounting systems are located. The number of spring mounting systems used depends upon the design of the engine. It is preferred to have three or four spring mounting systems for each displacer piston 12.

For each spring system, a flange 22 extends from the displacer piston 12. In this embodiment the flange 22 extends radially from a first wall 20a of the stepped portion, said first wall extending to a parallel to the displacer piston side wall 19.

the shaft 25 causing the first spring 27 to compress against the abutment flange 26 and allowing the second spring 32 to relax. As the piston 12 moves downwardly, so does the flange 22, thereby compressing the second spring 32. The shaft 25 may also be reversed so that the nut 31 is at the top, and flange 26 is on the other side of orifice 29.

Although the invention is described with reference to oscillation of the displacer piston in response to a pressure differential across the displacer piston, it could be effected by another perturbing force.

Fig. 3 shows an alternative spring maintaining arrangement using two compression springs. This arrangement differs from Fig. 2 in that the component which oscillates with the movement of the displacer piston 12 is the shaft 25. One end of the shaft 25 is attached to the displacer piston 12, preferably to the second wall 20b of the displacer piston stepped portion 20 which extends radially outwardly from the first wall 20a to the side wall 19. The second spring 32 extends between said second wall 20b and the cylinder block flange 28. The orifice 23 in which the shaft 25 is slidably located is provided in the cylinder block flange 28. The abutment flange 26 is provided at the other end of the shaft 25, so the first spring 27 extends between the abutment flange 26 and the cylinder block flange 28. This arrangement operates in a similar way as that shown in Fig. 2, whereby upward movement of the displacer piston 12 causes the shaft 25 to move upwards thereby causing the first spring 27 to be compressed between abutment flange 26 and cylinder block flange 28, whilst the second spring 32 relaxes. When the piston 12 moves downwardly, the second spring 32 is compressed and the first spring 27 relaxes, maintaining the overall force between the stepped portion second wall 20b and the

abutment flange 26.

A further alternative arrangement is illustrated in Fig. 4. This is an arrangement which works in a similar manner to that of Fig. 3, except in that the springs 27, 32 are located coaxially, rather than in series. In this arrangement, the cylinder block flange 28 is multi-stepped so as to provide two opposing abutment surfaces 33, 34. Thus the first spring 27 extends between one abutment surface 33 and an abutment flange 26 secured to an end of the shaft 25 by the nut 31. The second spring 32 extends between the other abutment surface 34 and projecting member extending from the stepped portion second wall 20b, from which the shaft 25 extends. Again, as before, each spring is precompressed by the other to eliminate the biassing forces. As the displacer piston 12 moves upwardly, so does the shaft 25 causing the first spring 27 to be compressed between the abutment flange 26 and the abutment surface 33 of the cylinder block flange 28 whilst the second spring 32 relaxes. When the piston 12 moves downward, the reverse occurs, substantially as described in connection with Fig. 3.

Referring now to Fig. 5, yet another alternative arrangement is shown, which is more similar in operation to the system shown in Fig. 2, except in that, again, the springs are co-axially located rather than in series. In this arrangement, as in Fig. 2, the cylinder block flange 28 has an orifice 29 for receiving one end of the shaft 25, to which is attached a nut 31.

Surrounding the shaft 25 is a cylindrical cup member 36 which has an orifice 37 in its base bordered by an upwardly projecting lip 38. Around the rim of the cup member 36 is a radially projecting flange 39 which forms an abutment surface for one end of the second spring 32. The other end of the second spring

32 bears against the cylinder block flange 28 biassing the flanges 28, 39 away from each other.

The first spring 27 extends between the base of the cup member 36 and an abutment flange 26 extending radially from the other end of the shaft 25. The cup member 36 is secured to the second wall 20b of the displacer piston stepped portion 20 by means of a plurality of studs 40 having a shoulder portion. The studs 40 are secured by means of nuts 41. Again, the first spring 27 is compressed as the displacer piston 12 moves upwardly, whilst the second spring 32 is compressed as it moves downwardly.

The arrangement of Fig. 6 differs from those of Figs. 2 to 5 in that extension springs are used instead of compression springs. In this arrangement, for each spring system, the cylinder block 10 is provided with a cylinder block flange 28 which projects radially inwardly. The flange 28 preferably has a stepped configuration as shown in Fig. 6 such that a section 42 is located between adjacent ends of the first and second springs 27, 32. The first spring 27 is attached at one end to the cylinder flange 28 and, at the other end, to the displacer piston 17, and preferably to a second wall 20b of the displacer piston stepped portion 20. The displacer piston 17 is thereby biassed towards the cylinder block flange 28. The second spring 32 extends between the cylinder block flange 28 and a flange 22 extending radially inwardly from the displacer piston 12. This displacer piston flange 22 includes means for attaching the other end of the second spring 32 to it. Thus, the displacer piston flange 22 is biassed by the second spring 32 towards the cylinder block flange 28. Each spring 27, 32 is pre-extended by the other, thus eliminating the biassing forces which would deflect the displacer piston 17 from its central position at rest. As the displacer piston 17 moves upwardly the

first spring 27 extends and the second spring 32 relaxes. As the piston 17 moves downwardly, the first spring 27 relaxes and the second spring 32 extends.

In an alternative embodiment shown in Fig. 7, two extension springs 27, 32 are again used. However in this case the displacer piston flange 22 is located at a position between the adjacent ends of each spring 27, 32, and one end of each spring 27, 32 is attached thereto. The other end of the first spring 27 is attached to one extension 42a of the cylinder block flange 28, which is located on one side of the spring system (in proximity to the second wall 20b of the displacer piston stepped portion 20). The cylinder block flange 28 has a second extension 42b, which is located on the other side of the spring system such that the other end of the second spring 32 is attached thereto by appropriate means 43. As before, as one spring extends under movement of the piston 12, the other spring relaxes and vice versa.

Some of the aforegoing configurations advantageously have minimum mass attached to the displacer piston 12, since in practical designs the weight of the displacer piston 12 is minimised.

The use of the nuts 31, 43 in the above-mentioned embodiments advantageously allow the adjustment of the displacer piston 12 centre position. The nuts 31, 43 also provide control over the alignment of the displacer piston 12 within the cylinder 11.

In the embodiments of the invention utilising compression springs, the ends are ground flat and parallel. These ground ends also help to maintain the alignment of the displacer piston 12 in the cylinder 11.

CLAIMS:

1. A Stirling engine having a cylinder block defining a cylinder, a displacer piston located in said cylinder and at least one spring mounting means provided to mount the displacer piston in the cylinder such that the displacer piston is free to oscillate in the cylinder in response to a pressure differential across the displacer piston, or other perturbing force, wherein the spring mounting means comprise at least two spring members arranged to bias the displacer piston towards a resting position with respect to the cylinder block, wherein the spring members are arranged such that the biassing force of one spring member counters the biassing force of the other spring member.

2. A Stirling engine as claimed in claim 1 in which the spring members are arranged in series.

3. A Stirling engine as claimed in claim 1 in which the spring members are arranged co-axially.

4. A Stirling engine as claimed in claim 1 in which the spring members are compression springs.

5. A Stirling engine as claimed in claim 4 in which the ends of the compression springs are flat and parallel.

6. A Stirling engine as claimed in any one of the preceding claims in which the cylinder block is provided with at least one abutment member for at least one of the spring members and the displacer piston is provided with at least one abutment member for at least one of the spring members, wherein one of the cylinder block and displacer piston abutment

members provides opposing abutment surfaces for two spring members, and in which one spring member extends between the cylinder block and displacer piston abutment members.

7. A Stirling engine as claimed in any one of the preceding claims in which the at least one abutment member of the displacer piston comprises flange means extending radially outwards from the displacer piston.

8. A Stirling engine as claimed in any one of claims 1 to 6 in which the at least one abutment member of the displacer piston comprises a portion of a radially extending wall of the displacer piston.

9. A Stirling engine as claimed in any one of claims 1 to 6 in which the at least one abutment member of the displacer piston is a member projecting from a radially extending wall of the displacer piston.

10. A Stirling engine as claimed in claim 9 in which the at least one abutment member of the displacer piston is provided by a cup member having an outwardly extending radial lip providing one abutment surface and having a base providing an opposing abutment surface.

11. A Stirling engine as claimed in any one of the preceding claims in which the at least one abutment member of the cylinder block comprises flange means extending radially inwards from the cylinder block.

12. A Stirling engine as claimed in any one of claims 6 to 11 comprising a further abutment member attached to a shaft, which shaft extends slidingly through one of the displacer piston or cylinder block abutment members, in which a second spring member extends

between either the displacer piston abutment member or the cylinder block abutment member and the shaft abutment member to bias them apart, wherein the shaft abutment member is constrained from moving more than a predetermined distance from either the cylinder block or the displacer piston abutment member.

13. A Stirling engine as claimed in claim 1 or claim 2 wherein the spring members are extension springs.

14. A Stirling engine as claimed in claim 13 in which one spring member extends between attachment means on the displacer piston and attachment means on the cylinder block, and a second spring member extends between either of said attachment means on the cylinder block or on the displacer piston and secondary attachment means on either the displacer piston or the cylinder block respectively.

15. A Stirling engine as claimed in claim 14 in which the attachment means on the displacer piston are located on a portion of a radially extending wall of the displacer piston.

16. A Stirling engine as claimed in claim 14 or claim 15 in which the attachment means and/or the secondary attachment means on the displacer piston comprise a flange member extending radially outwards from the displacer piston.

17. A Stirling engine as claimed in any one of claims 14 to 16 in which the attachment means on the cylinder block are located on a flange member extending radially inwards from the cylinder block.

18. A Stirling engine as claimed in any one of claims 14 to 17 in which the secondary attachment means on

between either the displacer piston abutment member or the cylinder block abutment member and the shaft abutment member to bias them apart, wherein the shaft abutment member is constrained from moving more than a predetermined distance from either the cylinder block or the displacer piston abutment member.

13. A Stirling engine as claimed in claim 1 or claim 2 wherein the spring members are extension springs.

14. A Stirling engine as claimed in claim 13 in which one spring member extends between attachment means on the displacer piston and attachment means on the cylinder block, and a second spring member extends between either of said attachment means on the cylinder block or on the displacer piston and secondary attachment means on either the displacer piston or the cylinder block respectively.

15. A Stirling engine as claimed in claim 14 in which the attachment means on the displacer piston are located on a portion of a radially extending wall of the displacer piston.

16. A Stirling engine as claimed in claim 14 or claim 15 in which the attachment means and/or the secondary attachment means on the displacer piston comprise a flange member extending radially outwards from the displacer piston.

17. A Stirling engine as claimed in any one of claims 14 to 16 in which the attachment means on the cylinder block are located on a flange member extending radially inwards from the cylinder block.

18. A Stirling engine as claimed in any one of claims 14 to 17 in which the secondary attachment means on

Amendments to the claims have been filed as follows

CLAIMS:

1. A Stirling engine having a cylinder block defining a cylinder, a displacer piston located in said cylinder having a heated end and a cooled end, and at least one spring mounting means provided to mount and centre the displacer piston in the cylinder such that the displacer piston is free to oscillate in the cylinder in response to a pressure differential across the displacer piston, or other perturbing force, the spring mounting means being located at the cooled end of the cylinder between the cylinder and the piston, said spring mounting means comprising at least two spring members arranged to bias the displacer piston towards a resting position centred with respect to the cylinder block, wherein the spring members are pre-compressed compression spring members or pre-extended tension spring members arranged such that the biassing force of one spring member counters the biassing force of the other spring member.

2. A Stirling engine as claimed in claim 1 in which the spring members are arranged in series.

3. A Stirling engine as claimed in claim 1 in which the spring members are arranged co-axially.

4. A Stirling engine as claimed in claim 1 in which the spring members are compression springs.

5. A Stirling engine as claimed in claim 4 in which the ends of the compression springs are flat and parallel.

6. A Stirling engine as claimed in any one of the preceding claims in which the cylinder block is provided with at least one abutment member for at least one of the spring members and the displacer

piston is provided with at least one abutment member for at least one of the spring members, wherein one of the cylinder block and displacer piston abutment